Jet Propulsion Laboratory, California Institute of Technology

Semi-analytic preliminary design of low-thrust missions

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Goal

"Implement a fast and intuitive strategy for preliminary low-thrust gravity-assist mission design"

Analytic solution with continuous thrust

Generalized logarithmic spirals. Integrals of motion.

Broad search

Branch and prune algorithm.

Local optimization of candidate solutions

Using MALTO.

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Contents

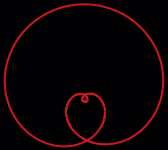
1) Generalized logarithmic spirals.
2) Individual legs.
3) The algorithm.
4) Branch and Prune.
5) Selection.
6) Examples:
   - Asteroid deflection.
   - Interplanetary mission.

Generalized log. spirals

Thrust profile

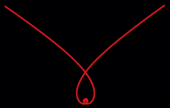
$$\mathbf{a}_p = -\frac{\mu}{r^2}\left[\cos\psi\,\mathbf{t} + (1-2\xi)\sin\psi\,\mathbf{n}\right]$$

Elliptic



Parabolic

Hyperbolic



Conservation laws

$$v^2 - \frac{2\mu}{r}(1-\xi) = K_1 \qquad \text{and} \qquad r v^2 \sin\psi = K_2$$

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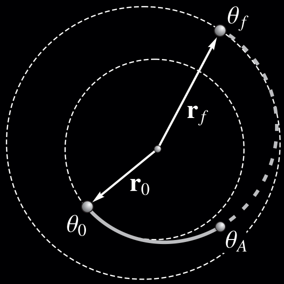
Individual legs

Targeting problem

$$r(\theta_f;\xi,\theta_A) - r_f = 0$$
$$t(\theta_f;\xi,\theta_A) - t_f = 0$$

- "Flyby mode".
- Lambert-like problem, 2 eqs. for 2 unknowns.
- Thrust + Coast / Coast + Thrust.
- Multirev solutions.



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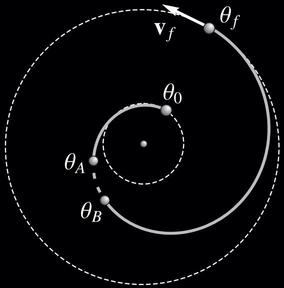
Individual legs II

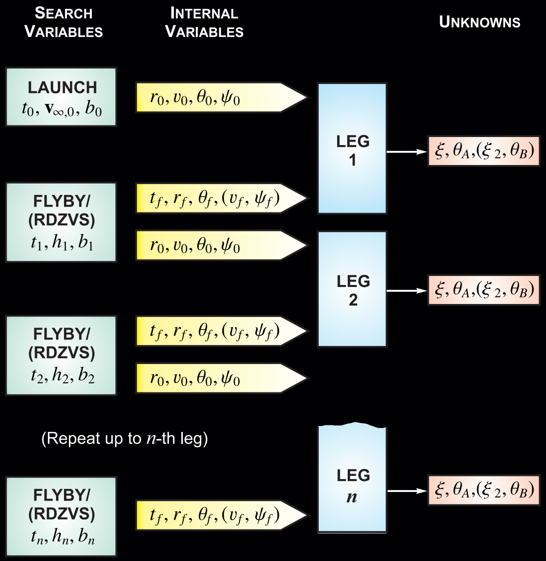
Rendezvous problem

$$
\begin{aligned}
r(\theta_f; \xi_1, \theta_A, \theta_B) - r_f &= 0 \\
t(\theta_f; \xi_1, \theta_A, \theta_B) - t_f &= 0 \\
\psi(\theta_f; \xi_1, \theta_A, \theta_B) - \psi_f &= 0
\end{aligned}
$$

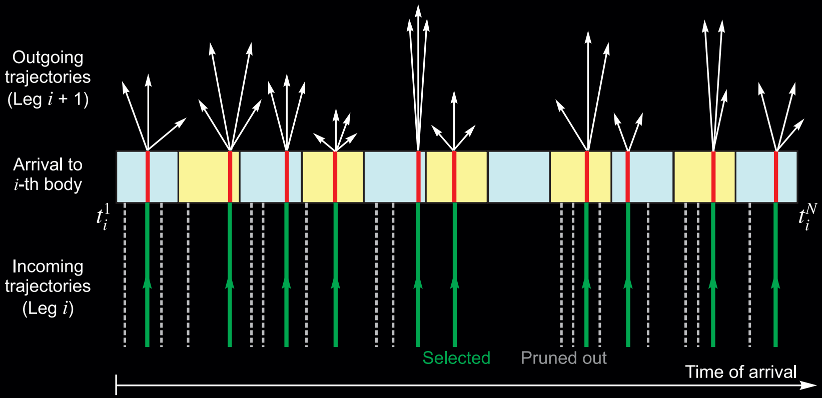
- Two additional constraints: (v_f, ψ_f).
- Thrust + Coast + Thrust.
- Condition on v_f can be solved analytically $\rightarrow$ 3 eqs.



The algorithm



Controls the dimension of the problem



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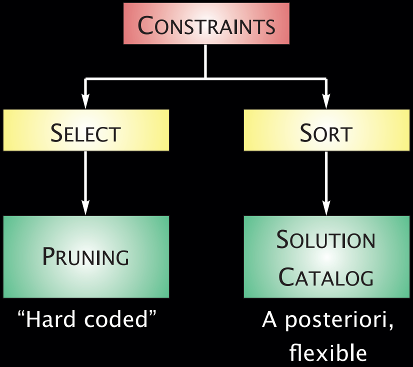
Selection



- Selection criteria during the search phase drive optimization step.
- Collection of solutions → post-process.
- Rank solutions for optimization stage.

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Examples

Asteroid deflection

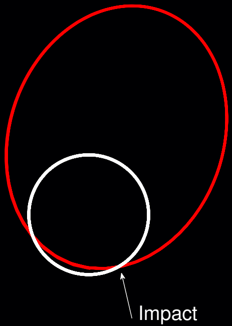
PDC2017 scenario

Interplanetary mission

Rendezvous with Jupiter

PDC2017

- Fictitious asteroid, impact July 2027.
- Discovered March 2017.
- Four periapsis passes: May-2017, Sep-2020, Feb-2024, Jun-2027.
- $\sim$1.5 yrs for earliest launch.
- Arrival phase angle $< 120^\circ$.



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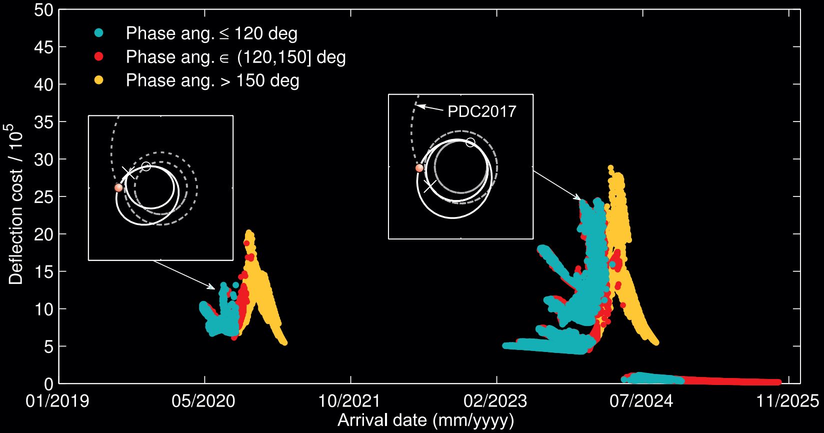
Earth–Venus–PDC2017

$$J = \beta(\mathbf{v}_\infty \cdot \mathbf{v}_{ast})\frac{m_{sc}}{m_{ast}}$$



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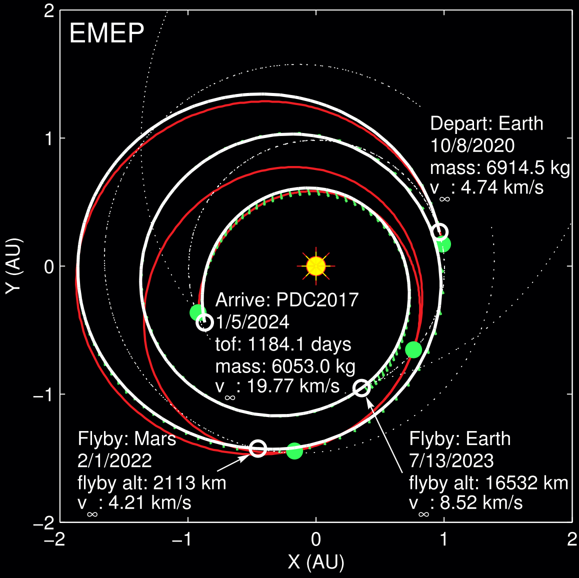
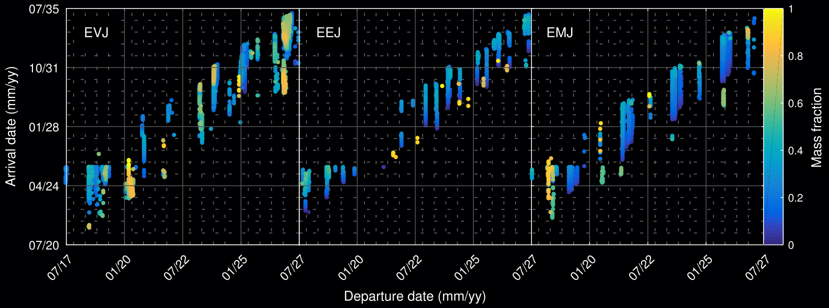
Asteroid deflection II



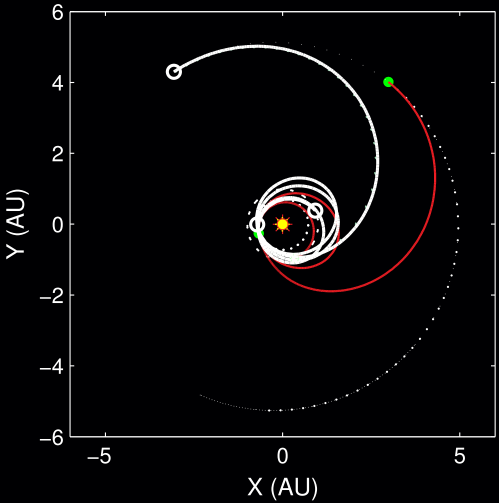
Missions to Jupiter

Single-flyby options



Missions to Jupiter II

Resonant flyby (Venus)



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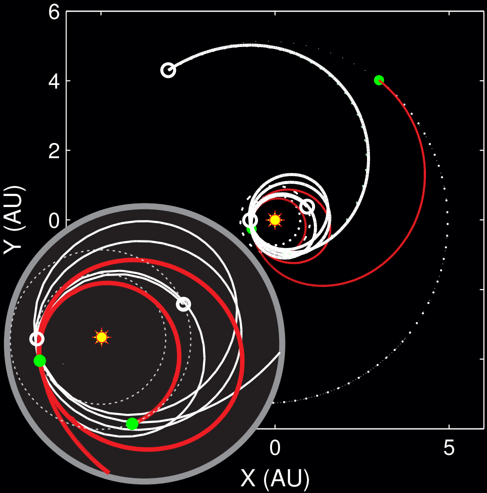
RESONANT FLYBY (VENUS)



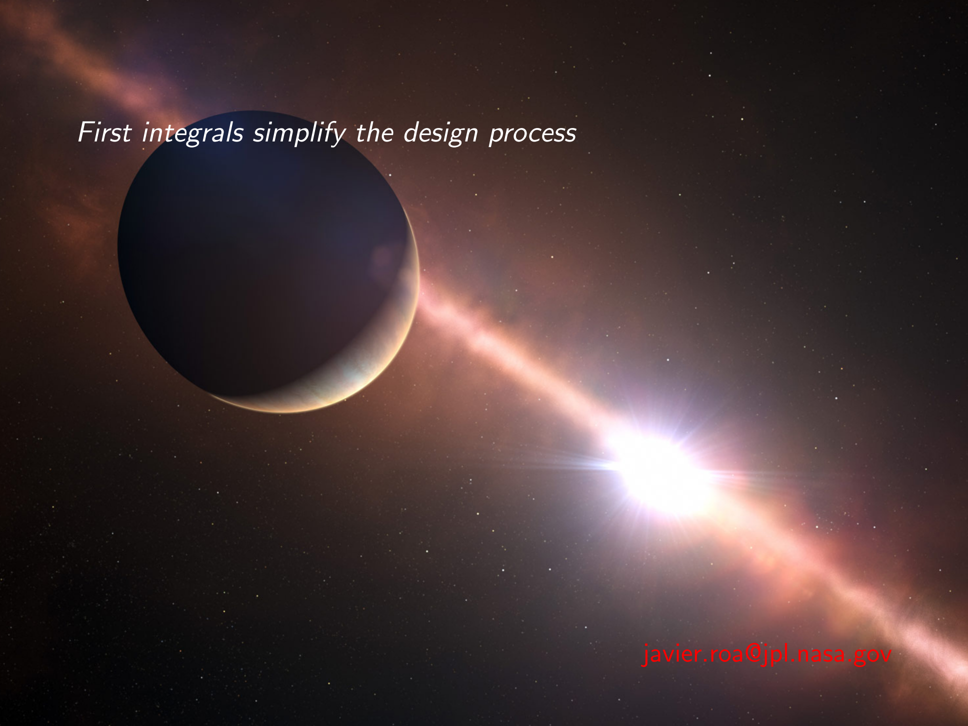
Conclusions

The method

- Conservation laws simplify the targeting problem.
- Computational burden: 2 or 3 equations per leg.
- Lambert-like methodology.
- Flexible: constraints + post-processing.

Results

- Generalized logarithmic spirals yield realistic seeds.
- The local optimizer converges from the initial guesses.



First integrals simplify the design process

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